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Summary

With U.S. sales approaching 50 million lamps per year, compact fluorescent systems are seeing increased application in the lighting of commercial interiors primarily as a conservation measure and an approach to reduce maintenance costs because they are longer-lived than incandescent sources. Lamp and fixture manufacturers, utilities, government agencies, and environmental groups have created programs designed to accelerate the adoption of compact fluorescent lamp (CFL) technology for commercial applications. However, efforts to accelerate the penetration of CFLs in the residential market have been narrowly limited to utility rebate programs for screw-based compact fluorescent technology. Concerns relating to performance, consumer acceptance and economics, suggest that screw-based (as opposed to pin-based) technologies are at best an impermanent and short-term approach to the ultimate, widespread residential application of the compact fluorescent lamp. The proper implementation of CFLs deserves attention not only because the technology saves significant amounts of energy, but also because CFLs have become a pervasive symbol for energy-efficiency.

This paper reviews some background on residential CFL applications, proposes a national program to accelerate the adoption of efficient CFL technologies in the home, and introduces strategies to bring about their success. This program is based on the premise that dedicated fixtures designed for the explicit operation of the CFL offer the most effective and permanent solution for efficient residential lighting.

Using pin-based lamps in dedicated fixtures allows for easy re-lamping with maximum economic benefits. It also ensures and maintains the full realization of the energy saving potential and lighting quality when displacing incandescent loads. Equally important, dedicated fixtures can be designed to optimize the performance of the CFL in comparison to fixtures intended for screw-based technologies. With these prospective benefits in mind a national program aimed at accelerating the use of CFL systems in residential applications should focus its efforts to promote dedicated compact fluorescent fixtures. Thus, the program should be a long-term effort addressing multiple issues in different market segments with the cooperation of various partners, including manufacturers, utilities, designers and consumer groups.

Dedicated CFL fixtures can find great success in the residential sector in much the same way as pin-based long fluorescent tubes displaced incandescents in the commercial sector in the 1940s, and pin-based halogen lamps swept into popularity in homes in the 1980s.

Context

Two cutting-edge regulatory issues in the energy-efficiency arena today are the verifiability and persistence of energy savings claimed for utility conservation programs. As regulatory scrutiny of utility DSM activities becomes more sophisticated, it is no longer sufficient to rely on simple "back of the envelope" engineering assumptions and calculations of energy savings. Such calculations can gloss over

critical characteristics of technology performance in the field and lead to unacceptable disparities between estimated and actual energy savings and cost effectiveness. It is critical that proponents of energy efficiency design their programs with sufficient integrity to resist such critiques. Utilities are increasingly concerned about these issues as their profit incentives for energy savings are shifted (via regulatory directives) from estimated to actual performance.

CFL systems are particularly vulnerable to criticism when improperly designed and installed. Specific choices from the CFL family of technologies can have dramatically different technical and economic performance, and not all of the technologies can pass the increasingly stringent regulatory tests. The differences among the options do not lie in the comparison of component efficiency (e.g. lamp efficacy, measured in lumens per watt) as much as in system performance characteristics, i.e. how well does the lamp system work when inserted into a fixture. In the case of CFL applications, comprehensive systems analysis must take into account (1) component aspects of lamps, ballasts, fixtures (optical and thermal performance), and product quality and durability; (2) user aspects (acceptance, and re-purchase vs. reversion to the inefficient alternative), and (3) the economic aspects based on the intersection of component and user effects. Moreover, when improperly applied, CFLs will not achieve their nominal performance rating and thus will fail to provide equivalent energy services (light output and quality) as the incandescent lamp they replace.

As an indication of the magnitude of some of these uncertainties, one large California utility today is required to assume a CFL service life of only 6,300 hours. This is a substantial reduction from the 10,000 hours typically assumed in back-of-the-envelope calculations of energy savings and cost-effectiveness.

Technology Options

Compact fluorescent systems can be classified into two types of designs: screw-based and pin-based fixture/luminaire systems.

1) Screw based retrofit systems

These systems typically include a lamp, ballast and a familiar threaded "Edison" base for "quick-and-dirty" interfacing with existing incandescent sockets inside fixtures. The lamp may be integral with the ballast or it may be removable for re-lamping. For several reasons, these systems should be viewed as a short-term solution for replacing incandescent sources.

Fixtures not designed specifically for the operation of CFLs may compromise performance, resulting in reduced perceived lamp brightness, and potential consumer dissatisfaction. Screw-based CFL technology may be difficult to justify in residential applications due to its higher price caused by a more complicated lamp, inclusion of ballast and Edison base, and shorter burning hours compared to commercial applications. Shorter burning hours and higher initial price lead to unacceptably long payback periods. These and other problems with screw-based CFLs are documented in a recent survey by the Electric Power Research Institute.

However, the fundamental reason why screw-based CFL technology is a short-term solution is the so-called "snapback" effect: when these units burn out--or perhaps even sooner--they can be replaced with the inexpensive incandescent lamp, eroding the conservation potential. This occurs in part because consumers will not generally keep $10-15 screw-based CFLs in the home inventory.

The push for "economy" has lead to the availability of some very inexpensive screw-based products that have marginal quality, leading to premature failures and compounded consumer dissatisfaction with the technology. There have been significant efforts as well to reduce CFL size so that they fit into existing home fixtures. Reducing dimensional characteristics can result in constricted ballast compartments that potentially compromise the quality and operation of the electronic components.

Perhaps the single largest barrier that needs to be addressed is consumer dissatisfaction with the new technology due to factors such as reduced brightness, poor light distribution, and premature failure.

Most existing home fixtures have been designed for the operation of an incandescent A-lamp with a very different luminous distribution from the more linear and non-symmetrical CFL. Replacing an incandescent A-lamp with a compact fluorescent will change noticeably the optical distribution of the overall fixture, potentially reducing perceived brightness and adding to consumer dissatisfaction. The critical consideration is that efficiency needs to be assessed using the total lumen output and light distribution of the fixture system where the lamp is installed, not just for the screw-based assembly by itself. Ultimately, consumers are interested in the total light output of the system and the quality of the illumination.

In summary, screw-based technology for the home is a short-term approach to improving residential lighting efficiency with CFLs, especially with low-quality products. The barrier of consumer dissatisfaction can be overcome only with the widespread availability to consumers of affordable, high-quality, aesthetically pleasing fixture/luminaire systems that are designed and dedicated specifically for the operation of the CFL.

2) Dedicated fixtures using pin-based compact fluorescent lamps

In contrast to the screw-based approach, dedicated systems include a fixture whose elements are electrical connections, ballasting, optical control and aesthetic integration. A separate replaceable pin-based lamp can be positioned appropriately to maximize optical distribution and maintain an optimum thermal environment. The pin-based lamp interfaces with a socket within the fixture as is typical of all commercial fixtures. Generally, the lighting community believes that dedicated systems will dominate in the future in both residential and commercial applications currently illuminated by incandescent fixtures.

Fixture geometry, the most important optimizing factor, can be designed to maximize the optical distribution of the unique compact fluorescent shape, thereby maintaining high fixture efficiency. In addition to performance issues, the biggest advantage over a screw-based system is that when the lamps burn out, the fixture can be re-lamped only with pin-based CFL, for continued savings. A pin-based compact fluorescent lamp is significantly less expensive than the more complicated screw-based system and it can thus be inventoried at home more economically. With dedicated fixtures, less solid waste is produced upon disposal, and mercury recovery is significantly less expensive than with screw based integral units.

Other advantages of pin-based systems include greater ability to address power quality issues in the ballast and easier implementation of dimmable ballasts.

Prompting Greater Adoption of CFLs

Proliferating CFLs successfully in residential applications will depend on:

1) effective education of consumers, retailers, designers, and builders
2) favorable consumer perceptions of costs and benefits
3) adequate product availability
4) high performance

Well-designed, dedicated pin-based fixtures can address the fourth above-mentioned criteria by providing for proper burning position, optics and high quality ballasting. Additionally, the cost-effectiveness of CFLs is improved by using pin-based lamps because they are significantly cheaper to

replace than integral screw-based systems. It is very difficult to address all of the these issues economically with screw-based technology.

The underlying goal of promoting pin-based dedicated CFL fixtures is to realize fully the conservation potential of displacing incandescent loads. Failures of inexpensive low-performance systems will cause consumer dissatisfaction and skepticism and hinder the successful penetration of CFLs. The only way to ensure that CFL technology's conservation potential is realized is to replace the incandescent lamp *and* socket with a dedicated fixture system. There are several successful examples of such an approach.

One is the lighting of the commercial interiors. Until the 1940s, all office interiors were illuminated with incandescent downlights. With the emergence of the fluorescent lamp, dedicated pin-based fixtures were produced, and eventually most commercial interiors converted to linear fluorescent illumination. We are now seeing a significant movement towards dedicated fixtures for commercial applications of the compact fluorescent lamp. The recessed downlight designed for compact fluorescent lamps is one of the largest growing fixture markets in United States. This type of thinking needs to be applied to the residential market.

In fact, successful CFL application is not limited to commercial interiors. One of the best residential applications is the outdoor fixture, because of its extended hours of operation. Currently, there are a variety of pin-based CFL outdoor fixtures on the market. These systems have been designed specifically for operation of the compact fluorescent lamp and they represent an excellent example of new fixture technology promoting successful residential penetration. Seeing the commercial possibilities, some manufacturers are developing dedicated fixtures for compact fluorescent lamps. Specific fixture types include CFL table lamps, surface-mounted fixtures for kitchens and hallways, sconces for wall applications, outdoor fixtures and recessed downlights. As with any new industry or product, these manufacturers depend on increased demand and acceptance of these fixtures in order to justify continued manufacture. By accelerating the use of dedicated fixtures, a national program can have real and sustained impact that sends a clear signal as to the commitment to high-quality long-term solutions.
The dramatic market success of pin-based halogen lighting in the residential sector is an indicator that consumers are able to accept new lighting approaches and hardware given a clear advance in technology or lighting quality. Compact fluorescent can offer some distinct advantages when installed in well designed fixtures. These advantages need to be clearly identified to consumers.

Programs for successful residential application of compact fluorescent lamps

An integrated long-term, approach can ensure the persistence and penetration of the compact fluorescent in residential applications. A program should be designed with a five- to ten-year time line starting now, and would accomplish the following key objectives:

1) Education and information on performance and application of CFLs. Major target groups include fixture manufacturers, the interior and architectural design community, utility planners, and most importantly, consumers.

2) Develop and accelerate the consumer availability of dedicated fixtures and pin-based lamps. This activity would improve coordination of the lamp, fixture and retail industry.

3) Encourage and motivate the use of CFLs through education programs, financial incentives, demonstration projects and building / energy codes. State and federal housing authorities could encourage the use of CFL technology

Course of Action

Suggested Program approaches and methodologies

Industry cooperation

- One goal of a national program should be to develop an advisory council consisting of fixture and lamp manufacturers, the lighting design and engineering community, and utility planners. Accelerating the compact fluorescent into the residential market will require significant industry participation. These groups need to be involved from the start.

- Coordinate activities with relevant technical groups and design associations including the IES, (Illuminating Engineering Society), ASID (American Society of Interior Designers), AEE (Association of Energy Engineers) and the AIA (American Institute of Architects). Additionally, the home building organizations, including the manufactured home industry and the NAHB (National Association of Home Builders) should be involved. Many of these groups have had experience in introducing new technologies to the home market. A national program could sponsor round-table discussions with the relevant associations to develop effective programs, strategies and education programs for builders and interior designers.

Information requirements

- Develop and sponsor a comprehensive study of residential lighting requirements and markets. Develop information on end-use patterns, market structure, and consumer buying habits. Coordinate activity with fixture manufacturers to help them target appropriate markets and develop marketing strategies.

- Develop and coordinate a comprehensive program of testing compact fluorescent systems in residential applications. Conduct a study of preferences and user satisfaction associated with various compact fluorescent systems and approaches. Develop programs to sponsor the installation of dedicated CFL fixtures.

Acceleration , development and application

- Offer significant financial incentives to fixture manufacturers to produce and market dedicated fixtures. For example, develop the "Luminous Carrot program" to encourage high-efficiency compact fluorescent fixtures for the home linking the industry, utilities and research community.

- Develop significant consumer rebate and financial incentive programs for the use of dedicated fixtures and coordinate this with demonstration projects. Balance the current rebate programs for screw-based technology with progressively increasing rebates for dedicated fixtures. In conjunction with this activity, develop a lamp availability program for pin-based lamps. All rebate activities should coordinate with educational programs, manufacturers, utilities and retailers.

- Sponsor national design competitions for the application and development of high-efficiency residential CFL fixtures. It could target specific fixtures types such as table lamps, or specific room application such as kitchens. This program could be supported and managed through the national IES, perhaps as part of their annual conference for additional visibility, and coordinated with rebate programs. The program should tie in with the lighting design community and have high visibility *via* the lighting and interior design magazines.

- Marshall the buying power of large purchasers. Buyer groups composed of home builders (manufactured and site-built), lighting retailers (e.g. Home Depot), housing management companies, and others could be assembled to collectively demand large numbers of very efficient products (and

thereby reduce the risk that fixture manufacturers must face when considering whether or not to modify their product line). Such buying activities could be linked to the above-mentioned design competitions.

- Develop energy use and cost labeling for fixture systems so that consumers could compare between incandescent and CFL fixtures in lighting stores, e.g. stating the annual operating cost for a given table lamp. The Federal Trade Commission's Energy Guide labeling system or the National Fenestration Rating Council model for windows may be successfully applicable to lighting fixtures.

Education and demonstration

- Develop coordinated programs with the lamp manufacturers and utilities to demonstrate advanced residential applications. Most manufacturers and utilities already have comprehensive educational demonstration centers and training programs that can be leveraged by a CFL program.

- Sponsor education programs with the national IES on dedicated fixtures. The IES has developed a comprehensive training and education program both nationally and by region.

- Sponsor demonstration programs for installing pin-based lamps and dedicated fixtures in high-visibility applications.

Institutional and Governmental leadership

- Develop and support a national technical center with an information dissemination program. This technical center should provide technical information on performance issues and help manufacturers and utilities develop high-efficiency dedicated fixtures. It should also provide useful information to the design community and consumer interest groups.

- Develop building codes that require the use of pin-based fixtures for residential construction. As one possible way to start, mandating the use of one dedicated compact fluorescent fixture per home in new construction would greatly accelerate the acceptance of compact fluorescent in the home and familiarity within the construction industry. This would also send a clear signal of commitment and market potential to the fixture and lamp manufacturers.

- The U.S. Department of Housing and Urban Development's public housing program could require the selective use of dedicated fixtures. This would greatly accelerate the widespread application of dedicated fixtures. These programs could tie in with a national competition where the winners receive contracts to provide the fixtures. With over one million housing units, the public housing market would provide a significant market for CFL fixtures, sending a clear message to the manufacturers.

Conclusion

Current efforts to accelerate compact fluorescent systems in residential application have been narrowly focused on rebate programs for screw-based CFL systems. Although, screw-based CFL systems provide an easy solution to replace incandescent lamps, and thus good initial penetration to the residential market, it is at best a short-term solution with several inherent technical and economic problems that severely limit the persistence of long term energy conservation in home. Dedicated fixtures using pin-based compact fluorescent lamps have the potential to successfully address the barriers in terms of economics, performance and aesthetics compared to the screw-based CFL systems. Because dedicated fixtures can be designed for the optimum optical and thermal performance of compact fluorescent lamps, they will be able to significantly improve consumer confidence in the new technology and in energy efficiency generally.

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